Online Track Reconstruction for the Mu3e Experiment

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for the Mu3e-Collaboration

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T 122.3
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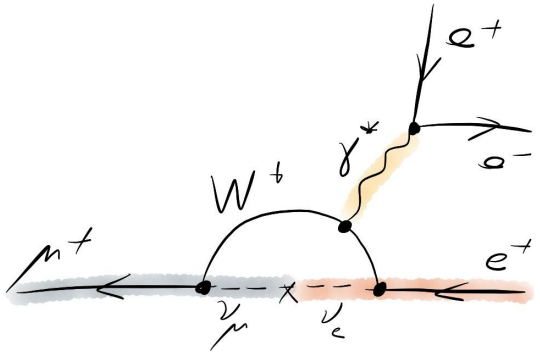
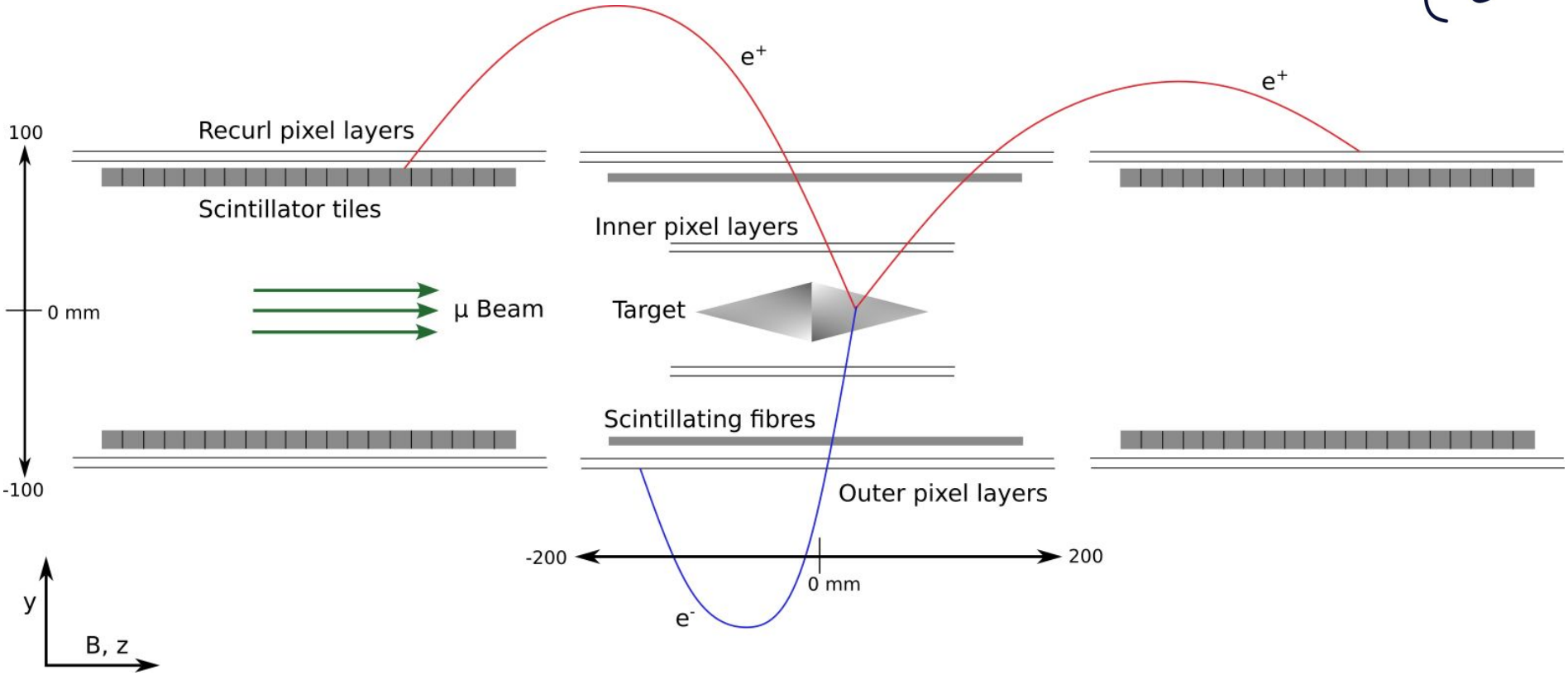
Mu3e Experiment



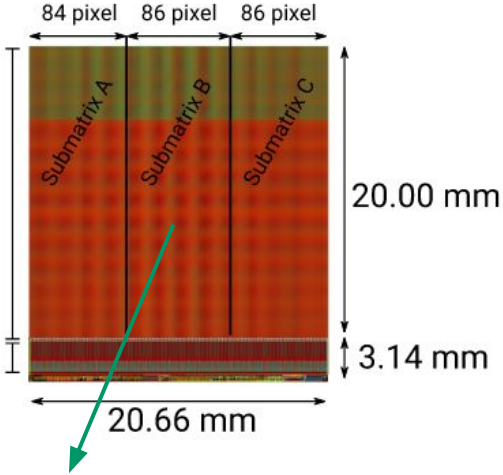
- We aim to observe or exclude the decay of a positive muon to two positrons and an electron.
- In standard model, possible via neutrino mixing but suppressed to unobservable level (Br < 10^{-54}).
- Observation would be a violation of the lepton flavour conservation.
- SINDRUM limit the sensitivity to Br < 10^{-12} (1988) PSI.
- Phase I - muon rate of $1x10^{8}$ s^{-1} and Br < $2x10^{-15}$.

Mu3e Detector



Detector Subsystems

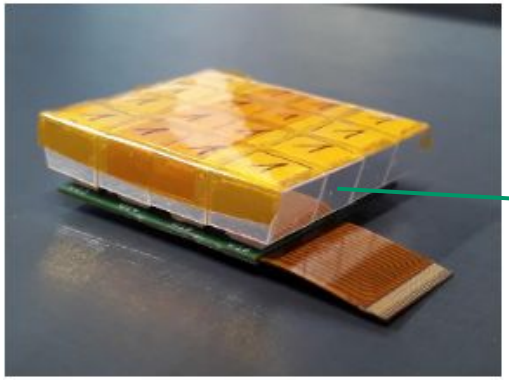
Tracking detector



MuPIX: High Voltage Active Pixel Sensors, pixels and the detector electronics are integrated into the same chip

Timing detector

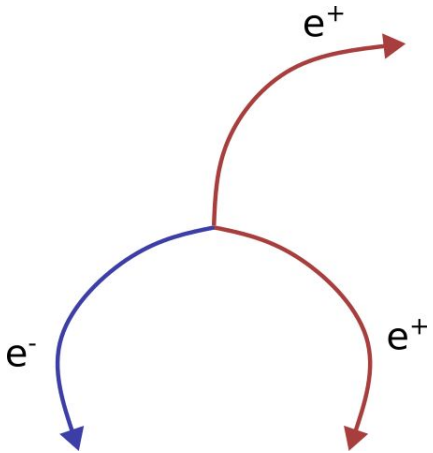
Scintillation fiber:
timing resolution is ~1 ns



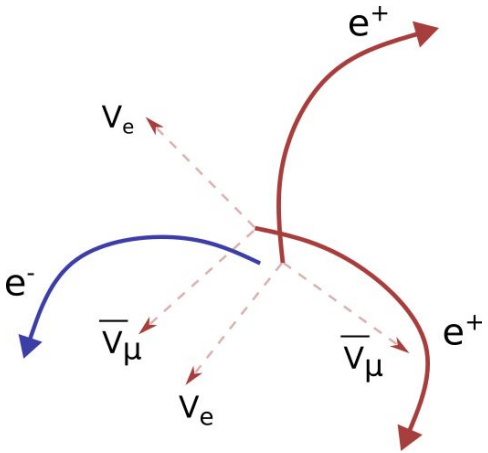
Scintillation Tiles: timing resolution about 70 ps

T 147.1 - *Measuring Large Energy deposition with HV-MAPS*
T 147.2 - *Charge Deposition and Charge Collection in HV-MAPS*

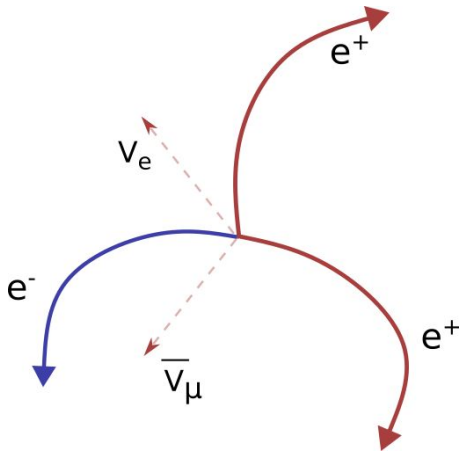
Signal and Background processes



Signal

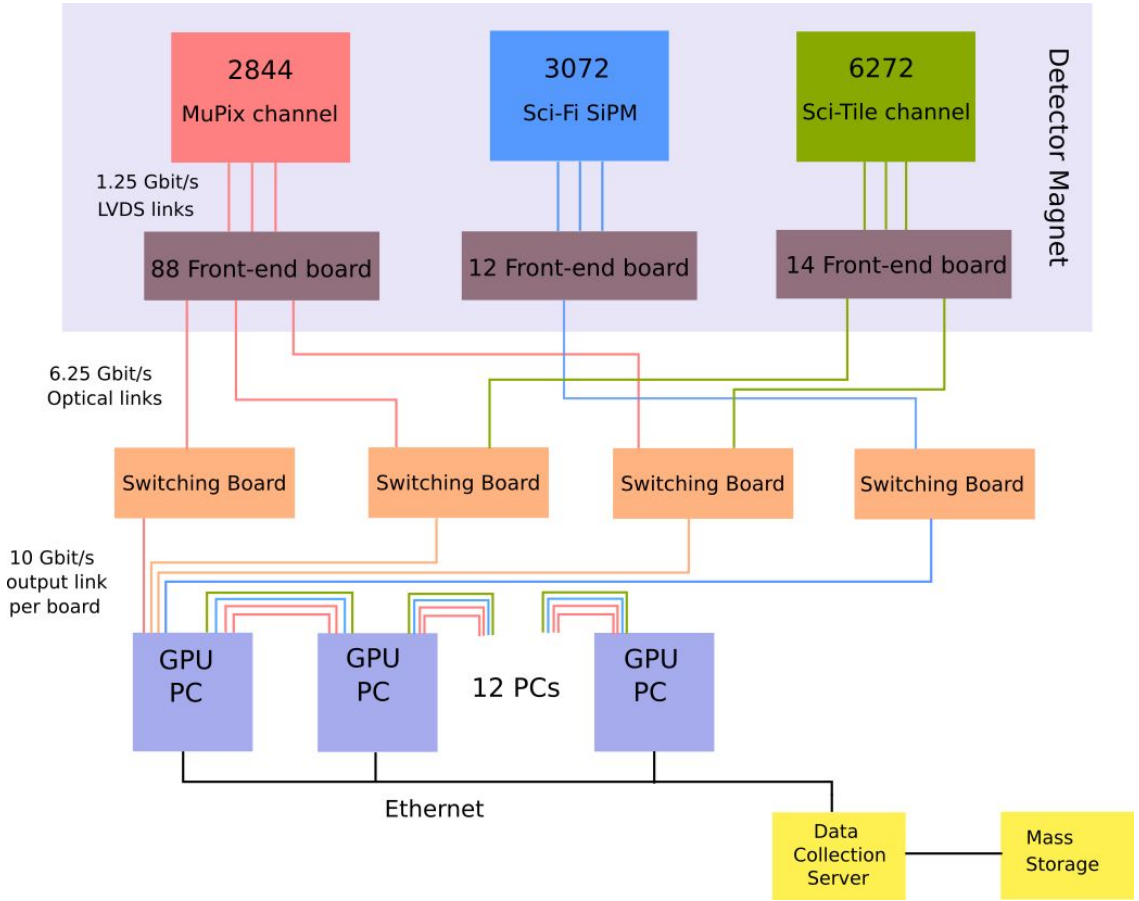


Combinatorial Background



Internal photon conversion
(Br = 3.4×10^{-5})

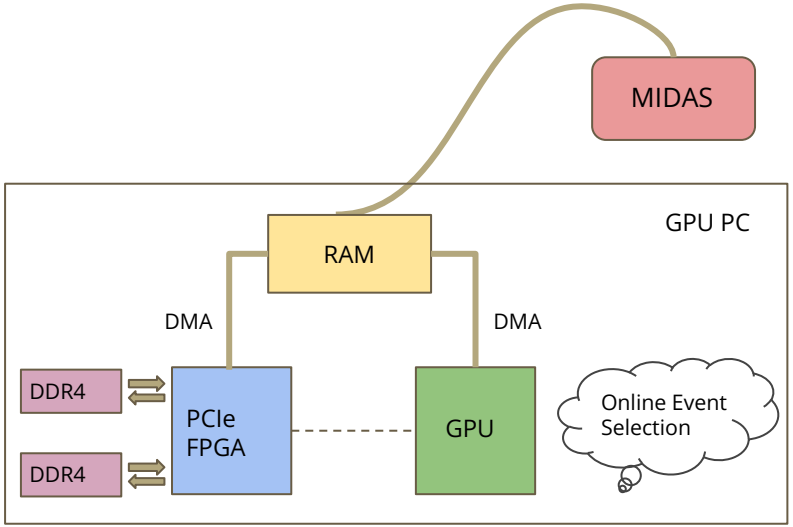
Readout System

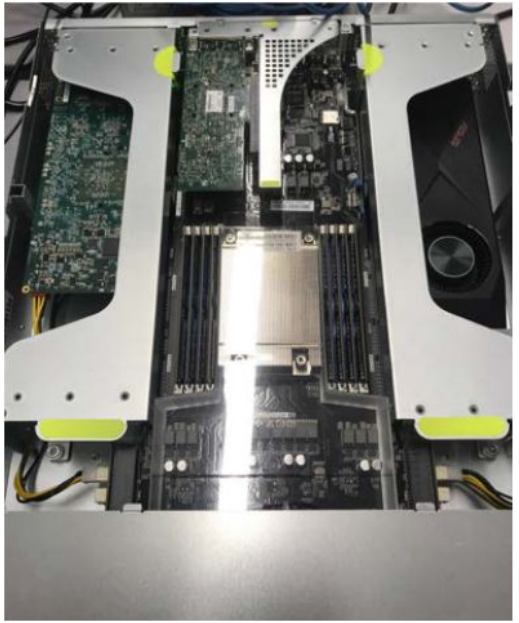


Detector	Rate (Gbit/s)
Pixel sensors	56
Fibers	28
Tiles	17
Total	101

Filter Farm

- Objective - select signal candidate events by reconstruction of tracks and vertices. To reduce data rate by a factor of 100.

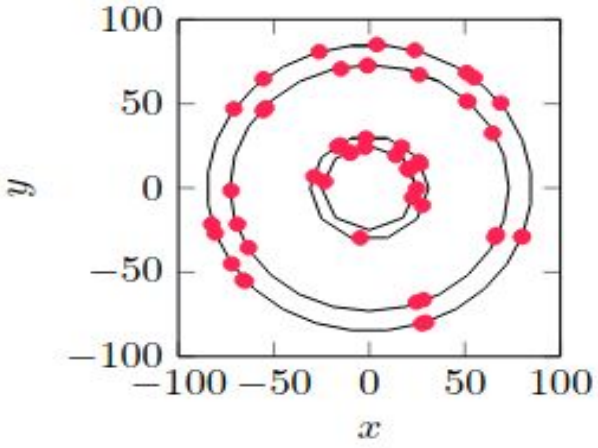


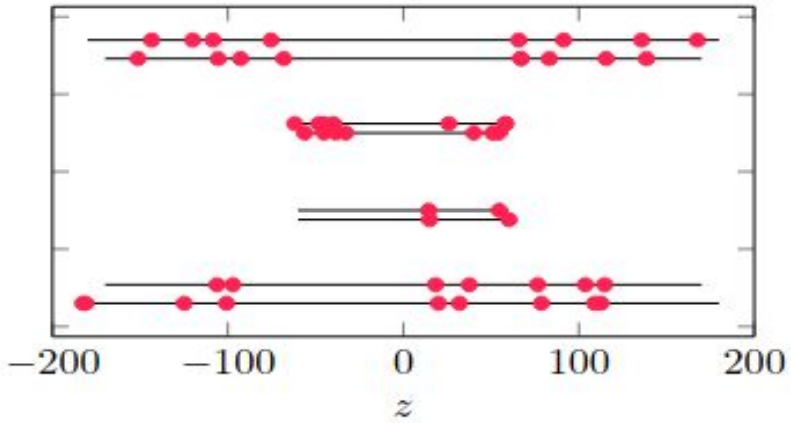


- NVIDIA GeForce RTX 3080 Ti.
- DE5a-NET FPGA card by Terasic.

Time Slices

- Each time slice is a snapshot of 64ns.
- Threshold performance - 1.5625×10^7 time slices per second.



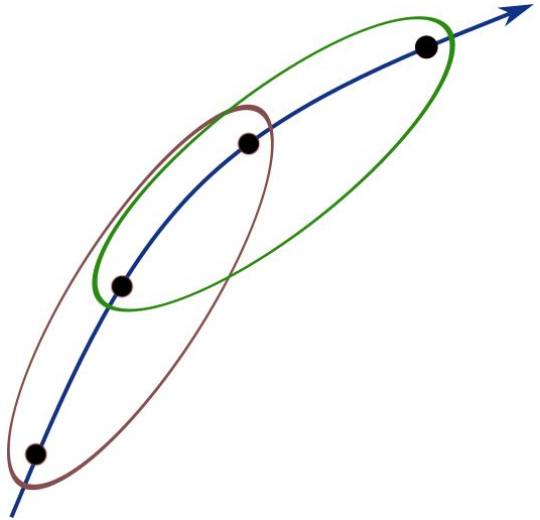


Online Event Selection

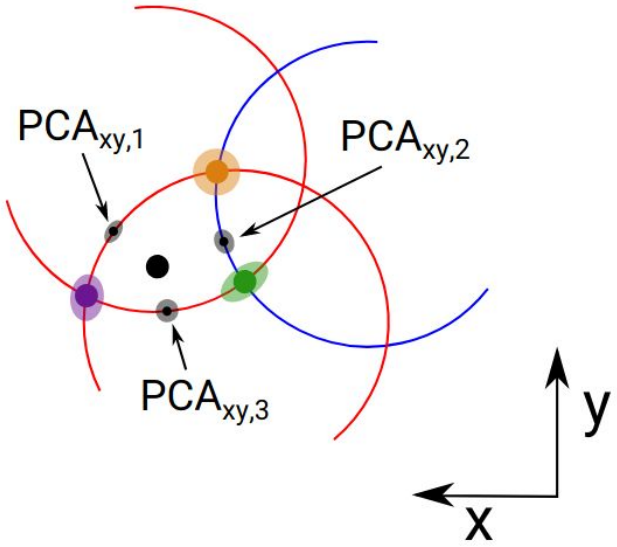
- Selection Cuts: Geometric cuts.
- Track Reconstruction: Hit triplet-based reconstruction.
- Vertex Selection: Reconstruction of possible event vertices.

Track Reconstruction

- 3D Multiple Scattering (MS) fit.
- Finds the curvature, minimising the MS angles for each triplet.
- Fits the triplets from first 3 layers after preselection.
- Helix trajectory is propagated to the 4th layer and the closest hit is found.
- The global curvature from both helix is used find the track parameters.

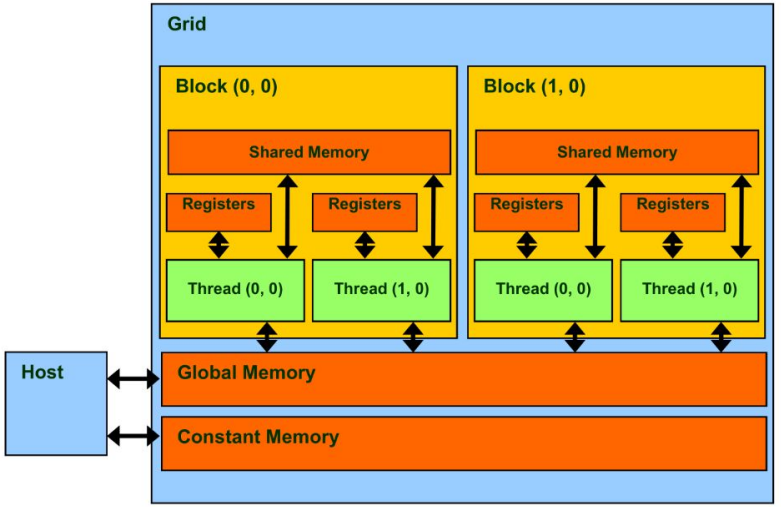


Vertex Selection



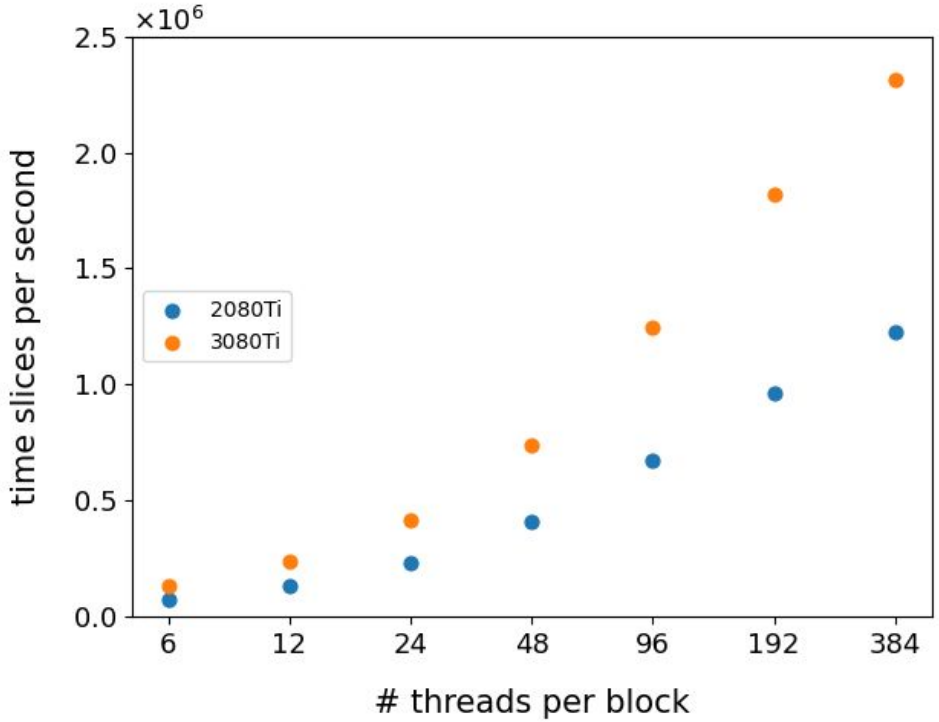
- With curvature the e^- and e^+ can be identified.
- Only when all three tracks intersect in the transverse plane then the weights are calculated.
- The weights are from the MS in the first detector plane and due to the pixel size.
- The total energy of all particles, must match the muons rest mass and total momentum is zero.
- Time slices with signal vertices are kept.

Parallel computing on GPU



- Each SM consists of 64 CUDA cores in 2080Ti and 128 CUDA cores in 3080Ti.
- Warps of 32 threads execute at once in streaming multiprocessors (SM)

Performance

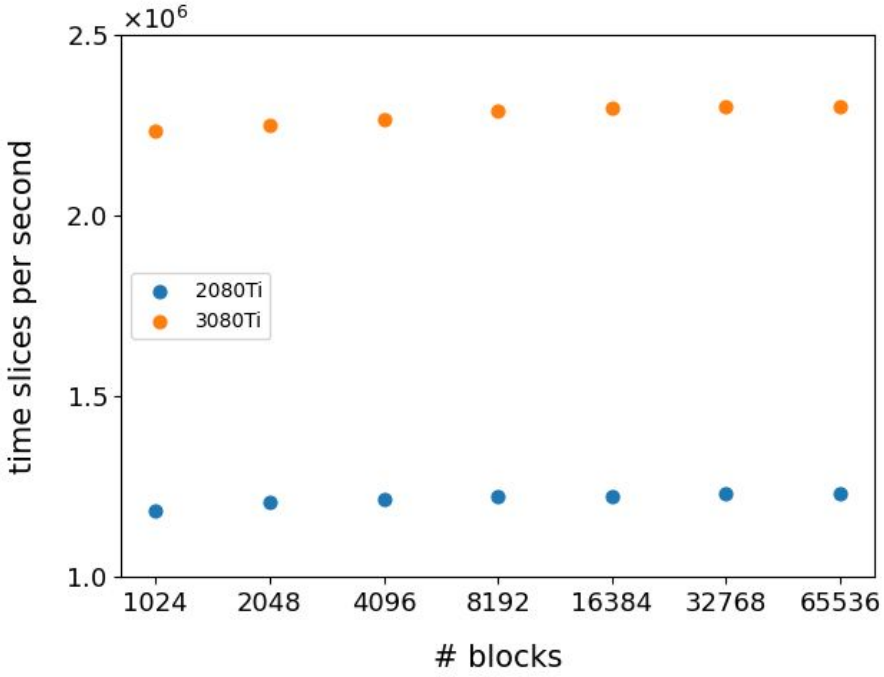


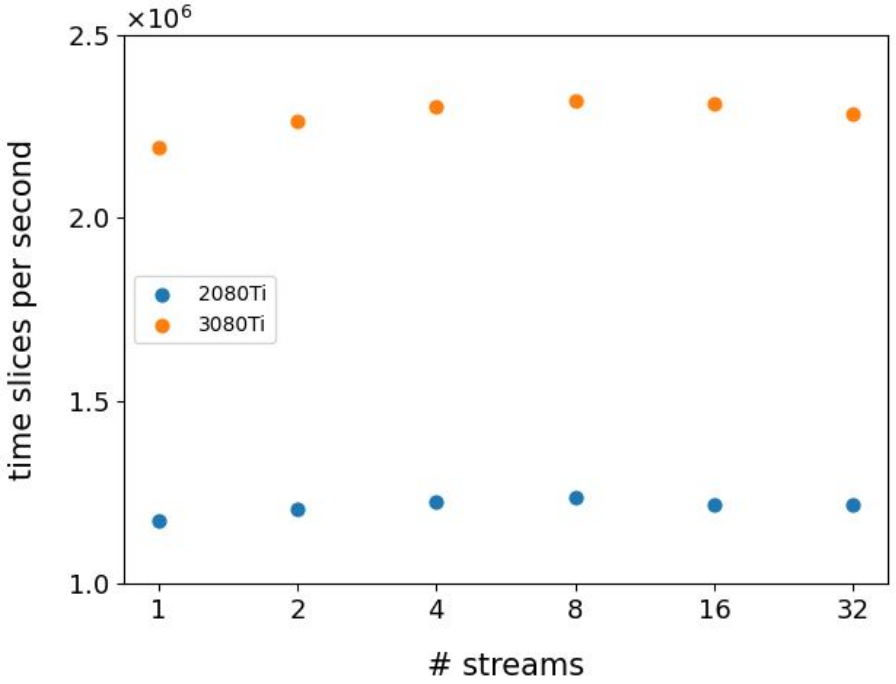
Conclusion

- Achieves a peak performance of 2.3×10^6 time slices per sec.
- Therefore, Phase I needs 7 GPU farms with NVIDIA Geforce RTX 3080Ti.
- Extra performance could be used to improve reconstruction efficiency.

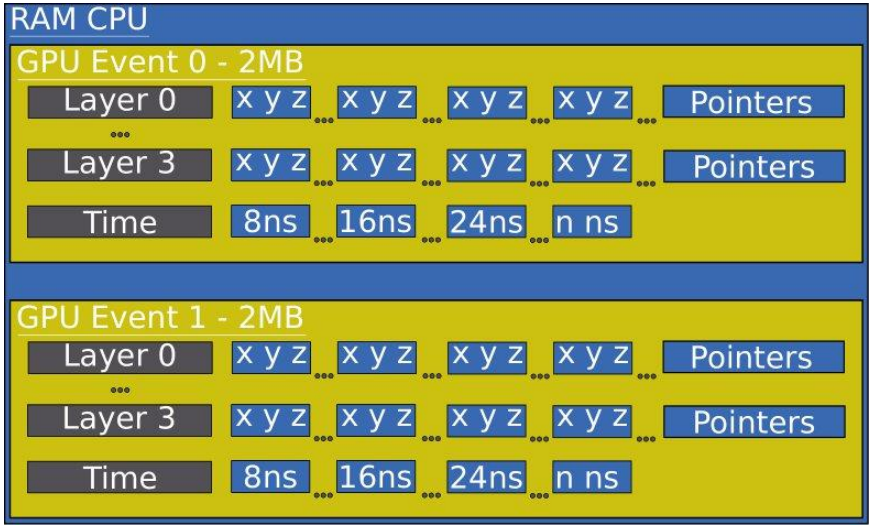
Backup

Performance





Global memory layout



Selection Cuts

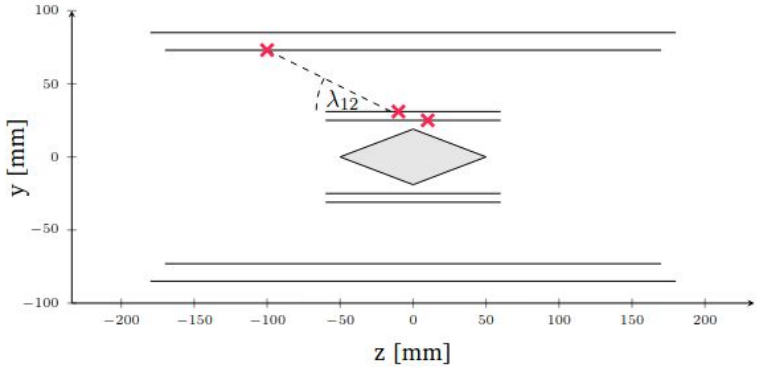
- Slope difference Δz between the slopes of consecutive layer hits in the longitudinal plane.

$$\tan \lambda_{ij} = \frac{z_j - z_i}{h_{t,j} - h_{t,i}},$$

$$\Delta\lambda = \tan \lambda_{12} - \tan \lambda_{01}.$$

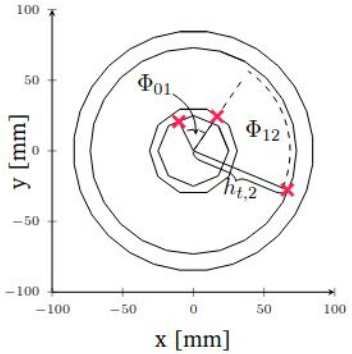
- In transverse plane we observe the angle Φ_{ij} between hits of two consecutive layers in relation the the origin:

$$\cos \Phi_{ij} = \frac{\mathbf{h}_{t,i} \cdot \mathbf{h}_{t,j}}{h_{t,i} h_{t,j}},$$



- $z_0 - z_1 < 30$ mm
- The transverse radius of the circle going through all three hits

$$r_{t,c} = \frac{d_{01} d_{12} d_{20}}{2[(\mathbf{h}_0 - \mathbf{h}_1) \times (\mathbf{h}_2 - \mathbf{h}_1)]_z},$$



Track Reconstruction

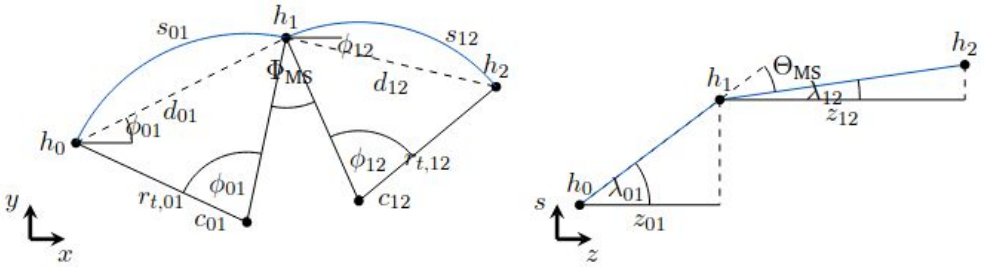
- For reconstruction Triplet fit is used.
- We search for the track minimizing the objective function. Assuming no momentum loss and thus a constant curvature k.

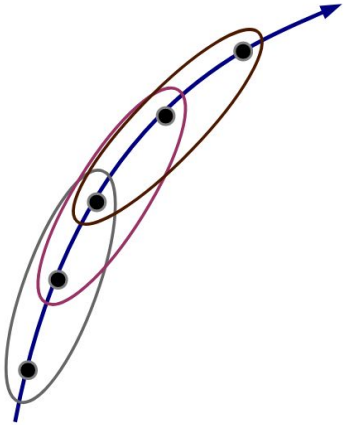
$$\chi^2(\kappa) = \frac{\Phi_{\mathrm{MS}}(\kappa)^2}{\sigma_\Phi^2} + \frac{\Theta_{\mathrm{MS}}(\kappa)^2}{\sigma_\Theta^2}.$$

- More than three hits for a full track fit requires to accommodate for multiple triplets.

$$\chi^2_{\mathrm{global}}(\kappa) = \sum_t^{n_{\mathrm{triplets}}} \chi^2_t(\kappa).$$

- A global curvature is found for all triplet combinations minimising the MS angles for each triplet.





Vertex Fit

- All combinations of two positrons and one electron are considered within each time slice. We calculate the total energy of all particles in the triplet using their curvature κ.
- The total energy of all particles, must match the muons rest energy.
- The weighted mean is calculated only if all three reconstructed tracks intersect and it is calculated for all combinations of three intersections from three tracks.
- The χ^2 for a vertex estimate is computed from the differences between the point of closest approach and the weighted mean both in the transverse plane and in the z-coordinate.